ANALYSIS OF TRANSIENT ACTIONS INFLUENCE IN POWER TRANSFORMER

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Abstract. *This article is focused on the theory of unacceptable effect on transformer winding, mainly the overvoltages and the mechanical forces. In the next part of the article is described the measurement of self-discharging voltage frequency dependence on transformer. The second measurement shows one of the possible type of SFRA method. The measurement results lead us only to the conclusion that some changes of the winding condition have occurred.*

Keywords

***Short-circuit, coil, transformer, winding, axial forces, radial forces, SFRA method*.**

1. Introduction

During the operation of transformer, different states, with dependences on their function can be created.

The transient actions (short-circuits and overvoltages) had main dependence on transformer insulation (coil varnish, paper and oil). Forces, which have mechanical effect on winding occur. In this case, the paper nuzzles and coil varnish are destroyed. Discharges changing the structure of oil appear in overvoltages.

The transient actions in transformer are created by each operation state change, connection the transformer on electrical power network, at fast load change, in short-circuit in network and the like. The electromagnetic effects have the influence on a transformer winding in transient actions, which need to analyses with special analyze, because they had serious importance for design and operation of transformer.

2. Short-circuits currents effect on transformer winding

The short-circuits in operation are commonly created by different line faults, etc. in mechanical damage of insulation, electric insulation, electric insulation breakdown on over voltage, wrong operation and in a next case row.

Meaning of the short-circuit is serious disrepair for the transformer, because there are high currents in it which are awfully rising winding temperature which can damage their insulation in affect. Much more dangerous are the high electro-magnetic forces, which might occur due to the devastation of transformer. Fig.1 presents a transformer with winding damaged by short-circuiting forces.

In such case the transformer winding and its coils must be structural and stable so it can tolerate high mechanical forces without the damage, which is created by short-circuits. In the transformers with self-cooling with aluminum, winding is necessary to prevent the unavoidable breakdown in operation time. In such case the choice of correct diagnostics is crucial to foresee the state.

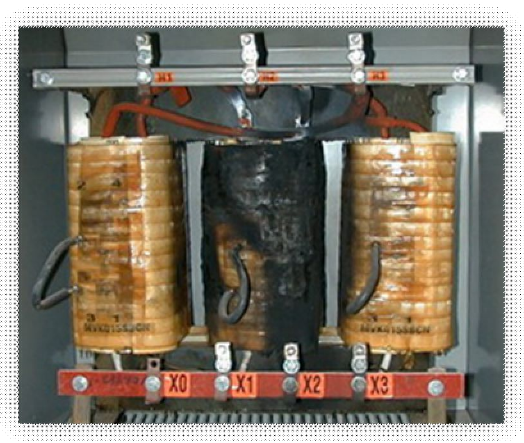

Fig. 1. View for defective transformer windings affected by short-circuits currents

The measure is based on two methods of monitoring and analyzing as well as their association for better identifies the most reliable image of the effects of short-circuit currents on transformer winding in operating time:

- monitoring of change of short-circuit voltage (impedance),
- monitoring of impedance or winding attenuation depending on the frequency by SFRA method,
- analysis of a winding state of winding phases and their correlative equation, e.g. by means of self-discharging voltage method.

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The state of the percentage changes in short-circuits voltage or impedance depending up frequency is the geometrical winding movement reflexing and their construction in transformer. The change of this state depends on thermal and mechanical effects of short circuit currents. For a better comprehension of the relation between transformer damage and short-circuits currents effects, one must focus on the effect of mechanical forces on transformer windings during short circuit.

3. The theory of mechanical forces effect on transformer winding during short-circuit

The primary cause of the appearance of forces, which affect the winding is the magnetic field influence on current flowing conductors. As to the transformer it is the field of stray flux.

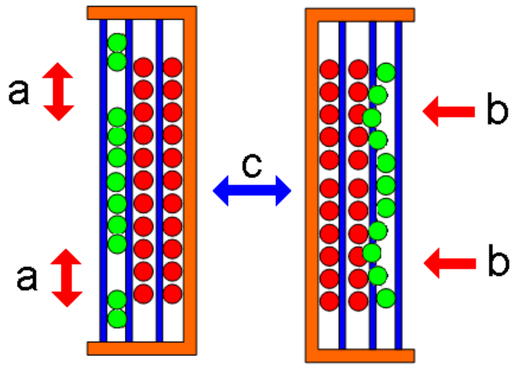

Fig. 2. Mechanical forces effect on transformer winding: a – axial forces affect, b – radial forces affect, c – normal winding (without force affect)

Under the state of normal operation, when the currents in transformer do not exceed rating value, the forces effecting on winding are generally of low level. But in short-circuits, when the currents reach the multiple of rating values, these forces can become dangerous for the windings or the confirmative construction.

We can divide forces affecting the windings into two groups (fig.2):

- radial (cross),
- axial (longitude).

3.1 Action of radial forces in winding

Radial forces F_q are a result of lengthwise fields, which are paralleled to axis of transformer winding. These forces are dilating external windings and compressing internal windings, as a consequence air spaces are bigger.

The lines of force of magnetic stray flux are parallel with axis of winding and similar to the effect of radial force on the each coil. The summaries of radial forces, which are signed as F_δ, lead to the increase of the space between windings δ (fig.3).

Infinite small change of magnetic field energy adequate to the infinite small rising space $\partial\delta$.

$$\partial w = F_\delta \cdot \partial\delta \text{ , from } F_\delta = \frac{\partial w}{\partial \delta}. \qquad (1)$$

Magnetic fields energy:

$$w = \frac{1}{2} \cdot i^2 \cdot \frac{1}{2\pi \cdot f} \cdot X_z , \qquad (2)$$

where: i – current momentary value in windings, X_z – leakage reactance in short of the windings, f – frequency,

so, force formula is:

$$F_\delta = \frac{\partial w}{\partial \delta} = 2\pi \cdot (it)^2 \cdot \frac{l_{str}}{L_u} \cdot 10^{-7} , \qquad (3)$$

where: (it) – coil ampere-turn, l_{str} – average winding length in, L_u is height of winding.

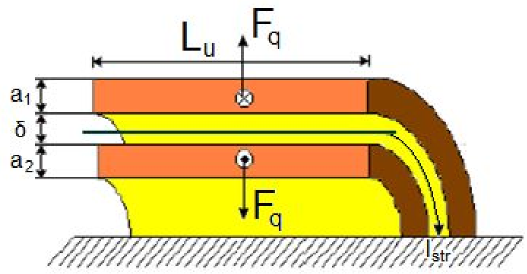

Fig. 3. Radial forces Fq (F_δ) effect on transformer windings

3.2 Action of axial forces in winding

The axial forces rise from the center to border of winding, where the magnetic field has the biggest cross component. In short-circuits axial forces can reach dangerous, so they can deform outer coil.

As to asymmetric windings axial forces are dangerous. The forces which are created by a small displacement of both coils, try to make this displacement bigger. This displacement can be created by coils which are not totally similar. The asymmetry can be also created by insulation of high voltage coil due to the fact that there are more insulators than in the lower voltage coil winding. But there is a possibility of the retraction of any side of insulation in adequate coils. This retraction can by caused by drying-out.

According to [2] one needs to pay more attention to catching outer coil. In case of released coil, the axial forces F_d (fig.4) can cause displacement of outer coils to the vertical sides (fig.4 shows the origination of empty spaces). The redundant pressure of spacers can press insulation and move winding, which can cause serious damages of transformer.

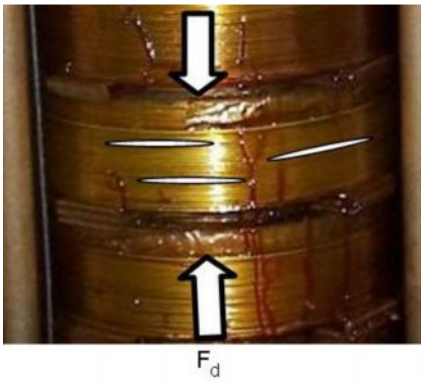

Fig. 4. The Pressurize the coil conductors by excessive effect of axial forces pressing. (influence on the deformation of insulation)

4. Experimental analyses

4.1 Self-discharging voltage method

Senses self-discharging voltage is highly sensitive method which is based on assessment of the quality changes of material aftermath operational aging. [5]

After closed defined time of the inter-coil capacitance charge the transformer is unplugged from DC supply and we measure discharging process of winding insulation through leakage resistance. Faster decreasing of self-discharging voltage is caused by smaller value of insulating resistance. Discharging process is affected by irreversible degree of degradation of material too.

The graph of voltage on inter-coil capacitance of transformer after unplugging is showed on fig.5. Discharging time is grows with rising quality of insulation of windings.

We can observe differences between each phases of transformer in t_2 time in this measuring.

This difference between transformer phases is an important sign of degradation of state of winding insulation by short-circuits currents effect in main.

We checkup 9 randomly selected transformer, which was used in distribution network with power in range from 30 kVA to 1 MVA and we acquire discharging time for each phase (tab.1). The results of measurements were partial image of short-circuits stresses of transformer in operating time. Coils were not changed before test.

In tab.1 are values obtained by measuring the self-discharging voltages on primary HV coils. Comparison of the different phases shows asymmetry of quality of insulation on transformers 1 and 4.

Tab. 1. Results of discharging time measurement

No.	Type	*S*	A - B	A - C	B - C	IΔt_v.100I	Note
		kVA		t_v (s)		(%)	
1	kTO 253/22	30	48	34	48	21,54	*a
2	aTO 294/22	100	98	82	96	10,87	
3	aTO 294/22	100	114	98	103	8,57	
4	aTO 294/22	100	103	131	156	20,77	*a
5	aTO 334/22	250	152	131	159	11,09	
6	aTO 334/22	400	68	71	69	2,40	
7	aTO 374/22	630	135	107	123	12,05	
8	aTO 374/22	1000	76	60	63	14,57	
9	kTO 350/22	400	165	165	171	2,40	

*a – **huge inter-coil difference**

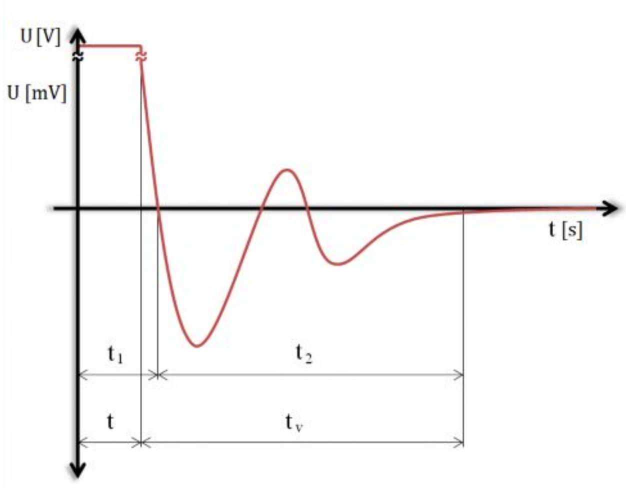

Fig. 5. The discharge process of transformer after disconnection from DC supply

4.2 SFRA method

SFRA (Sweep Frequency Response Analyzer) method belongs to current most effective analyses and allows detection the influences of short-circuit currents, overcurrents and other effects damaging either winding or magnetic circuit of the transformer. This all can be performed without the necessity of decomposition of device and subsequent winding damage determination, which is very time-consuming.

SFRA as a one of the most predictable methods, can be based on passive parameters measurement method depending on frequency 20Hz – 200kHz (see fig.6. and 7 - measured values for distribution transformer 22/0,4 kV).

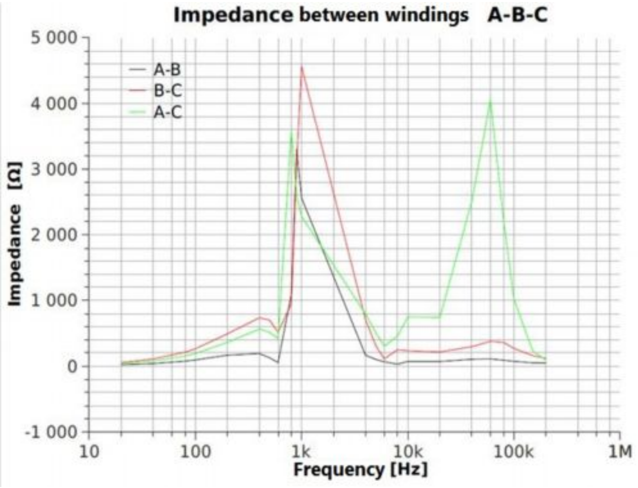

Fig. 6. Dependence of impedance in frequency, which was measured for transformer 22/0,4 kV

During these measurements are detected a mechanical states of tested winding and ferromagnetic core. The obtained curves typical for this measurement provide the important information about changes in the core, which are visible in low frequencies, while higher frequencies are linked to problems such as winding movements or turn-to-turn fault.

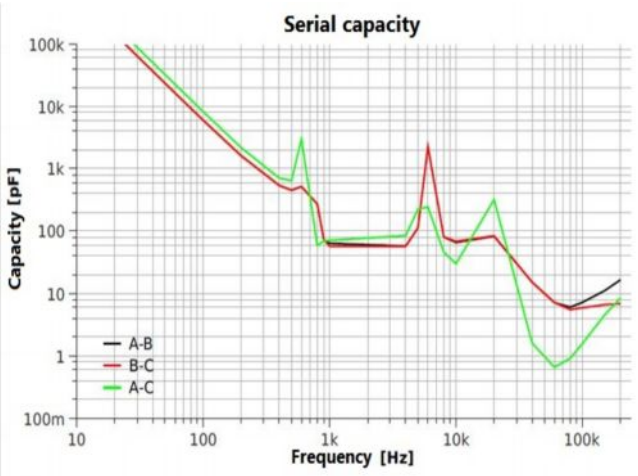

Fig. 7. Dependence of capacity on frequency which was measured for transformer 22/0,4 kV

The application of analysis of phase or tgδ (dissipation factor) attenuation depending on frequency (fig.8) is suitable for more complete evaluation of winding condition. This analysis enables to assess the processes of winding movements during the particular short-circuits influences.

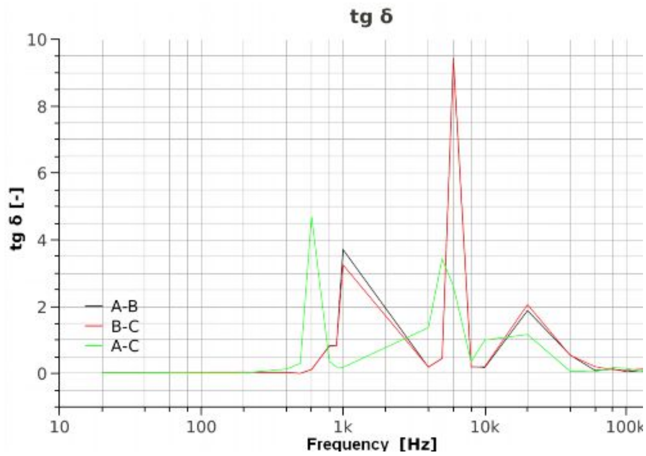

Fig. 8. Dependence of tgδ on frequency which was measured for transformer 22/0,4 kV

5. Conclusion

A relation between the response and the winding condition is definite, otherwise it is complicated. It is impossible to expect the assessment of concrete damage of winding from differences in response behaviors. The measurement results lead to the conclusion that some change of winding condition really occurred. Such test results are very helpful to decide, whether it is unavoidable to open and revise the transformer or not.

The state of the response depending up frequency is the image of geometrical winding movement and their construction in transformer. The change of this state depends on thermal and mechanical effects of short circuit currents.

Problem of the frequency analysis of transformers by SFRA method is very comprehensive and its application becomes interesting for many transformer manufacturers and operators. From the long-term point of view the SFRA method is supposed to be very useful and it provides enough information on tested transformers. These transformers have their reference data obtained by the manufacturers, suitable for the comparison with further data of particular transformer.

SFRA testing method represents one of the most effective alternative diagnostic methods compared to visual check. This method allows to detect the effects of the short-circuit currents, whereas we are able to evaluate the mechanical strength action on the transformer winding during previous operation It is also possible to identify the specific winding phase, which has been mostly influenced by the short-circuit currents, without a necessity of transformer dividing, which would be very time consuming.

Acknowledgments

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